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DUST CONCENTRATIONS AS A FUNCTION OF AIR VELOCITY IN MINES - APPLICATION OF CONTINUOUS DUST SENSORS AND AN AEROSOL COUNTER

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MAY 1984

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SEP 24 1984
MICROMEDIA

14 pp

MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT MRP/MRL 84-72 (TR)

DUST CONCENTRATIONS AS A FUNCTION OF AIR VELOCITY IN MINES -APPLICATION OF CONTINUOUS DUST SENSORS & AEROSOL COUNTERS

by

S.G. Hardcastle*

ABSTRACT

Improving dust control and reducing dust concentrations are major objectives in underground mining. The effects of air velocity and associated parameters on dust concentrations are well recognized but have only been subject to a few selective studies; these have been predominantly concerned with optimum air velocities and with dust sedimentation in coal mines. These two areas and others concerning the mechanics of dust transportation warrant furtner investigation in order to optimize dust control in hard and soft rock mining. To aid such investigations continuous real-time dust sensors and multi-size range aerosol counters, as are being acquired at the Elliot Lake Laboratory, are invaluable.

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Effets de la vitesse de l'air sur les concentrations de poussière dans les mines - Utilisation de détecteurs de poussière et de compteurs aérosols à fonctionnement continu.

par

S.G. Hardcastle*

Résumé

L'amélioration des méthodes relatives au contrôle de la poussière et à la réduction du niveau des concentrations de poussière sont les principaux objectifs visés dans l'exploitation des mines de charbon souterraines. Bien que les effets de la vitesse de l'air et autres paramètres soient bien connus, les quelques études sur le sujet ont surtout porté sur les vitesses d'air optimales et la formation de la poussière dans les mines de charbon. Ces deux derniers éléments ainsi que les éléments ayant trait au mode de transport de la poussière méritent une étude approfondie afin d'optimiser les méthodes portant sur le contrôle de la poussière dans l'exploitation minière de la roche tendre et de la roche dure. Les détecteurs de poussière fonctionnant à temps réel en continu et les compteurs aérosols à champs d'action multiples comme ceux que le Laboratoire d'Elliot Lake s'apprête à acquérir sont d'une valeur inestimable.

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INTRODUCTION

Dust in the mining environs is undesirable. It is a constant area of concern predominantly because it can promote and cause diseases in the respirable system, and is generally regarded as a nuisance.

Dust is an unavoidable by-product of mining for the majority of extractive techniques employed. As a result of this, one of the main functions of mine ventilation is to dilute dust in the working place to a safe concentration. Evidence of dust being a physiological hazard to man can be dated back to Egyptian mummies from 3,000 B.C. Dust associated diseases, relating to mining, were referenced by Agricola (1) in the sixteenth century. Since then, references have also been found in the eighteenth and nineteenth centuries, but it was not until the present century that the hazards of dust were given any prominence.

Dust attributable diseases in mining were first acknowledged in South Africa in 1912 when controlling and compensatory legislation were introduced.

Since 1912 the physiological hazards of dust have been accepted world-wide. A major concern in mining, at present, is reducing the mining workforce's exposure to dust-laden atmospheres and the concentrations thereof.

A dust concentration is a function of the amount of dust produced by mining operations entering an airstream and the quantity flow of that airstream. In reducing dust concentrations there has been a disproportionate major thrust to reduce dust production with a few selective studies into the airflow parameters.

VENTILATION AND DUST

Ventilation is a prerequisite of any underground mining environment. Apart from being necessary to supply oxygen to the working personnel, it also acts as a dilution medium for the diverse pollutants that result from mining. These pollutants include: gases, heat and humidity, and dust.

Each pollutant has a maximum allowable concentration in the working environment, such that it is safe or equitable for the personnel therein (2). This requires minimum quantities of ventilation to provide the desired dilution ratio. With greater productivity from improved methods of mining underground minerals and increasingly higher mechanization, the pollutant production inevitably increases. This is especially pertinent to gases and heat, hence the air quantity needed for dilution also increases.

To provide a greater air quantity to a working place generally requires an associated increase in the air velocity. This is beneficial to most pollutants with the exception of dust, as many of the properties controlling the mass of dust in an airstream are velocity dependent.

The relationship of air velocity on the mechanisms of dust transportation, which controls the dust mass flow rate, is of primary importance in determining dust concentrations. In evaluating these mechanisms continuous real-time dust monitors and multi-size range aerosol counting systems would be invaluable.

DUST MASS FLOW RATES AND AIR VELOCITIES

The dust mass flow rate and the airflow rate determine the mass concentration of dust in air. Where the airflow rate is increased the dust concentration will decrease proportionally only if the dust mass flow rate has not also increased as a function of the change in air velocity. However, where dust mass flow rates are related to air velocity, the dust concentration will only improve as long as the relative increase in dust mass flow rate is less than the relative increase of air velocity. Airborne dust occurring in mines can generally be sub-divided into two epidemiological size classifications:

i) Respirable dust <5 μm, this is the most dangerous as it can be retained in the lungs to cause a fibrotic reaction resulting in pneumoconiosis.

ii) Coarse dust >10 μm, combined with air velocity this size can cause discomfort on impaction against the face or into the eyes (3,4,5).

The primary parameter controlling the dust mass carried by an airstream is the settling velocity of the entrained particles. For respirable dust the terminal settling velocity is very low, <0.2 cm/s, therefore any respirable dust introduced into an airstream can generally be assumed not to settle out even at low velocities. Conversely for coarse dust, the terminal settling velocity is much quicker, possibly 1 m/s, thus the time such dust remains airborne and the distance travelled through the workings are both short. Consequently when air velocities are increased, the coarse dust is transported through longer lengths of a ventilation system and increases the concentrations in those extended lengths.

In addition to natural sedimentation, dust deposition from the airstream is enhanced by: turbulence, impaction against and adherence to obstructions, coalescence, changes in airflow direction, and changes of airway cross-sectional area.

Opposing deposition mechanisms, dust mass flow rates can be increased by: dust pick-up from sedimented sources on the surfaces of an airway, and increased entrainment efficiency at a dust source with a change of airflow distribution resultant from a change of velocity. Both of these should be minimized to avoid increases in dust mass flow and hence the dust concentrations.

Investigations into pick-up velocities of dust have shown widely differing optimum velocities to avoid increasing dust mass flow rates. Laboratory tests with respirable coal dust in wind tunnels (6), have given optimum velocities of 1.5 to 2 m/s before significant dust pick-up occurs. Other work in coal mines has given values of up to 6 m/s but the generally accepted maximum is 4 m/s.

It is also apparent that moisture content has a significant effect on pick-up velocities as it increases the adherence between particles and tends to promote the formation of aggregates. This has been quantitatively demonstrated in laboratory tests and underground (7).

Further work is necessary to gain a fuller understanding of the effects of air velocity on dust pick-up, especially in non-coal mines. Investigations should be performed in situ where naturally occurring sedimented deposits of dust form in preference to possibly unrepresentative deposits in wind tunnels.

DUST TRANSPORTATION BY AN AIRSTREAM

The time during which dust remains airborne is inversely proportional to the settling velocity of the particles which is dependent on size, density and air viscosity. However, although velocity is a prime factor, turbulence, impaction, bends, cohesion and changes of the cross-sectional area of the airstream also affect the dust concentrations.

This has been demonstrated in coal mines by Ford and Reinhardt (8,9). Investigations have shown that various proportions of a dust cloud will be deposited out to varying degrees, as it passes through a workplace, in proportion to the dust's size. In 300 m of return roadway directly after the face, respirable dust concentrations have been shown to reduce by 35 to 55% and coarse dust 60 to 90%.

Similar reductions of dust concentrations have also been observed in faces and intake airways of coal mines. To date no similar work has been found to have been performed in non-coal mines.

In all the investigations of dust transportation cited, it is also apparent that the rate of increase in the total deposition of dust tends to exponentially decrease as distance from the dust source initial measuring point increases. An explanation of this could be that initially the larger size particles are being predominantly deposited; then as the age of the dust cloud increases, the composition tends to become finer, thus the relative reduction rate decreases. A more detailed analysis of investigations into the relationship of dust concentrations versus air velocity and dust transportation, has been previously reported by the author (10).

THE APPLICATION OF MICROPROCESSOR CONTROLLED DUST SENSORS AND AEROSOL COUNTERS

Virtually all the cited investigations into dust transportation and the inter-relationship of air velocity and dust pick-up have been performed with gravimetric dust samplers. Such units are not ideally suited to this work as these commonly collect a time-averaged sample with no indication of concentration variability during the sample time.

To avoid the time period smoothing associated with many gravimetric samplers, these should be replaced by continuous real-time monitors. Such monitors have the advantage of giving an historic display of the distribution of changes in the ambient dust concentration.

Currently available real-time dust monitors operate by a different principle to gravimetric samplers; they work on a light scattering or diffraction technique. The resultant reading taken by the monitors is then a function of particle size and not its weight, but such monitors depending on the light optic configuration can be size-selective. Also most real-time monitors are passive and do not retain a sample for subsequent analysis.

Time-based outputs of instantaneous concentrations are invaluable in the following areas of study:

i) correlating high (or low) dust concentrations to specific operations of mining;

ii) determining decay rates (or growth rates) of dust concentrations;

iii) determining time lag in dust transportation between measuring stations;

iv) quantifying the contribution of high dust concentrations to subsequent parts of a ventilation network;

v) investigating deposition rates for invididual high and low dust concentration states;

vi) evaluating the efficiency of a ventilation or dust extraction system in diluting or removing dust.

Commonly used gravimetric samplers are designed to collect dust over the whole respirable range, 0.5 to 6 μm; many of these units are unable to give an intermediate size distribution unless subsequently analyzed. To gain a size distribution, a number of samplers could be set up to collect different small fractions of the respirable range; this however can introduce errors through each sampler collecting from a possibly non-uniform cloud. To avoid this error and the need for multiple samplers, the use of a single multi-size range counter is advantageous.

Available aerosol counters, again using a light detection method, can analyze a common cloud virtually simultaneously for particles of up to five selectable different diameters. Commercially available aerosol counters also have the advantage over gravimetric or other multi-size range samplers of being virtually real-time units; they can give an almost instantaneous size distribution of a dust cloud and be programmed to take a time-based series of readings and effectively operate as a continuous monitor.

Being able to obtain instantaneous size distributions of a dust cloud would be invaluable in the following studies:

a) Determining the dust size output of specific mining operations.

b) Evaluating filtration system efficiency with respect to dust size.

c) Determining specific size concentration contours across roadway sections.

d) Evaluating changes in dust cloud composition as affected by dust pick-up or deposition.

Both real-time dust monitors and microprocessor controlled multi-size range aerosol counters are presently being produced under, or proposed for, development contracts from CANMET.

CONCLUSIONS

The occupational hazards of dust exposure to mining personnel are well recognized. To assess personnel exposure extensive studies have been performed.

Resulting from studies it has become evident that the most dangerous size range of dust is 0.5 to 6 μm, and that any concentration of this respirable range is potentially injurious to health. Thus a great emphasis has been allocated to reducing the danger, through positive dust control techniques, and has been extremely successful. General methods employed have been: improvement of machinery to reduce dust production, improvements in ventilation to dilute concentrations, and dust supression and filtration to reduce dust mass flow rates.

To date most methods of dust control have been evaluated by their effect on the whole respirable size range of dust. However, further improvement of the efficiencies of these methods requires a greater understanding of the mechanisms which control dust concentrations. For this it may no longer be possible to treat the respirable range of dust as a whole, but be necessary to break it down and investigate the individual effects of any dust control method on much smaller width size ranges. This will be aided with the use of multi-size aerosol counters.

Similarly, long-period averaged samples taken by gravimetric methods, may no longer be adequate in evaluating dust concentrations. Rather real-time dust monitors should be used to highlight high concentrations when these occur, such that they may be easily recognized and minimized.

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